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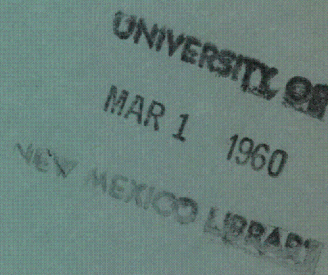
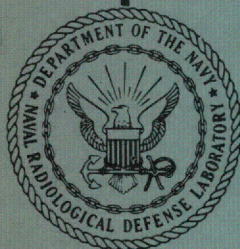
AN ALPHA SURVEY RADIAC FOR FIELD USE

Research and Development Technical Report USNRDL-TR-326

14 May 1959

by

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G. Kiyoi



U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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AN ALPHA SURVEY RADIAC FOR FIELD USE

**Research and Development Technical Report USNRDL-TR-317
NE 051500**

14 May 1959

by

**K. Sinclair
G. Kiyoi**

Instruments

**Technical Objective
AW-5a**

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ABSTRACT

An alpha survey radiac employing a photomultiplier tube and scintillation detector has been developed. The instrument utilizes transistor circuitry and operates from two standard flashlight batteries. Four linear ranges are provided with full scale indication on the highest range corresponding to $10,000 \mu\text{g} / \text{m}^2 \text{Pu}^{239}$. The instrument was designed with a separable probe and a telescoping extension for easier ground monitoring. A thorium metal source is attached to the instrument housing for checking instrument calibration in the field.

The device conforms satisfactorily to the military requirements for altitude, humidity, vibration, shock, and storage. The operational battery life is in excess of 40 hours. Instrument error at low temperatures slightly exceeds the $\pm 20\%$ accuracy requirement; however, adequate measurements are readily made by using the thorium check source to provide a check point. Instrument response to low energy X-rays is excessive. However, tests indicate that a simple lead filter will eliminate this difficulty.

SUMMARY

The Problem

To design and fabricate an alpha survey radiac with a greater range capability than the present AN/PDR-10 alpha survey meter. The device must be superior in performance and reliability and suitable for use in a wide range of field environments.

Findings

A self-powered, portable, alpha survey radiac has been developed that represents a significant improvement over the AN/PDR 10. The instrument is packaged in a form that permits ease of operation and field maintenance. Transistor circuitry is used throughout, and power is furnished by two flashlight batteries. The instrument conforms satisfactorily to the general requirements for military radiacs and to specific operational requirements of alpha monitoring.

ADMINISTRATIVE INFORMATION

Background of Work

During FY1958, this Laboratory prosecuted the problem "Alpha Survey Instrument" with the primary objective to study existing alpha survey instruments and their inadequacies and to determine the features which are desirable in laboratory and military field alpha survey instruments. This problem continued during FY1959 under the title "Scintillation Counter and Accessories" with an objective to develop and engineer an alpha radiac with superior reliability and performance characteristics suitable for use in a wide range of field environments and meeting present operational requirements.

Authorization and Funding

These problems were authorized by the Bureau of Ships Radiac Program, R & D Project No. NE 051500, Technical Objective AW-05601a, subtask 823-2.11 "Development of Improved Alpha Survey Meter", details of which are contained in the U.S. Naval Radiological Defense Laboratory (USNRDL) Technical Program for FY1958 as Program 11, Problem 3, "Alpha Survey Instrument" and in the USNRDL Technical Program for FY1959 as Program B 6 Problem 1, "Scintillation Counters and Accessories". Funding for these problems was supported by the Bureau of Ships on allotment 70-178/58 for FY1958 and allotment 70-178/59 for FY1959.

Project Personnel were:

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Detector Fabrication Techniques	R. W. Welch

Acknowledgement

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1. INTRODUCTION

The RAS-10 is a general purpose alpha radiac utilizing scintillation detection and transistorized circuitry. Its principal function is the detection and measurement of alpha particles incident to the detecting screen. The limitations of existing alpha radiacs have necessitated the instrument development outlined here. The existing military device, the AN/PDR-10, is an air proportional instrument of very limited field utility due, primarily, to its inherent sensitivity to humidity.¹ In addition, present operational needs,² based on special nuclear weapons, have created a requirement for a device of far greater range capability than the AN/PDR-10. Four linear ranges are provided on the RAS-10 with a full scale indication on the most sensitive range corresponding to about $10 \mu\text{g}/\text{m}^2$ of P^{239} and full scale indication on the least sensitive corresponding to $10,000 \mu\text{g}/\text{m}^2$. On the other hand, the AN/PDR-10, without modification, provides a maximum reading corresponding to only $5 \mu\text{g}/\text{m}^2$ of Pu^{239} . This limitation, coupled with the other problems inherent in its design, seriously restricts its usefulness as a military field instrument. The radiac described on the following pages is intended to overcome these problems.

2. GENERAL DESCRIPTION

The RAS-10 is packaged in a rather unusual fashion (*see Fig. 1*) to meet the special requirements of alpha monitoring. Since the range of alpha particles in air is short, on the order of two inches for 6.3 Mev particles, every effort must be made to permit convenient operation of the instrument in close proximity to the surface being surveyed. Consequently, the unit was designed with a separable probe assembly usable as a flexible hand held unit or at the end of a telescoping extension for ground survey while walking erect (*see Fig. 2*). The circuit is completely transistorized except for the PM tube and operates from two standard size 'D' cells. Four switch selected ranges are available: 0-1000 CPM, 0-10,000 CPM, 0-100,000 CPM and 0-1,000,000 CPM. The overall screen area is 60 cm^2 with about 20 cm^2 of actual active counting area distributed over the surface (*see Fig. 3*). A thorium metal source, approximately the same size as the screen, is attached to the instrument housing to provide a means for checking instrument calibration and performance in the field (*Figs. 4 and 5*).

3. THEORY OF OPERATION

The circuit of the RAS-10 is shown in block form in *Fig. 6*. An alpha particle, with energy greater than the detection threshold (about 3 Mev), incident at the silver activated ZnS screen produces a light pulse. The light is conducted by means of a lucite "light pipe" to the photocathode of the photomultiplier (PM) tube (type 931-VA) where it causes the emission of photo-electrons. These in turn produce many more electrons in traversing the multiplier by secondary emission at each of the dynodes. The initial light pulse then results in a substantial circuit pulse at the anode of the 931. A transistor emitter-follower located at the phototube housing serves as an impedance converter providing a low impedance output to drive the cable to the main instrument box. All signals arriving at the Schmitt discriminator with voltages in excess of the pre-set trigger level cause an output pulse from this stage. The resultant negative pulse is inverted in the next stage and then drives

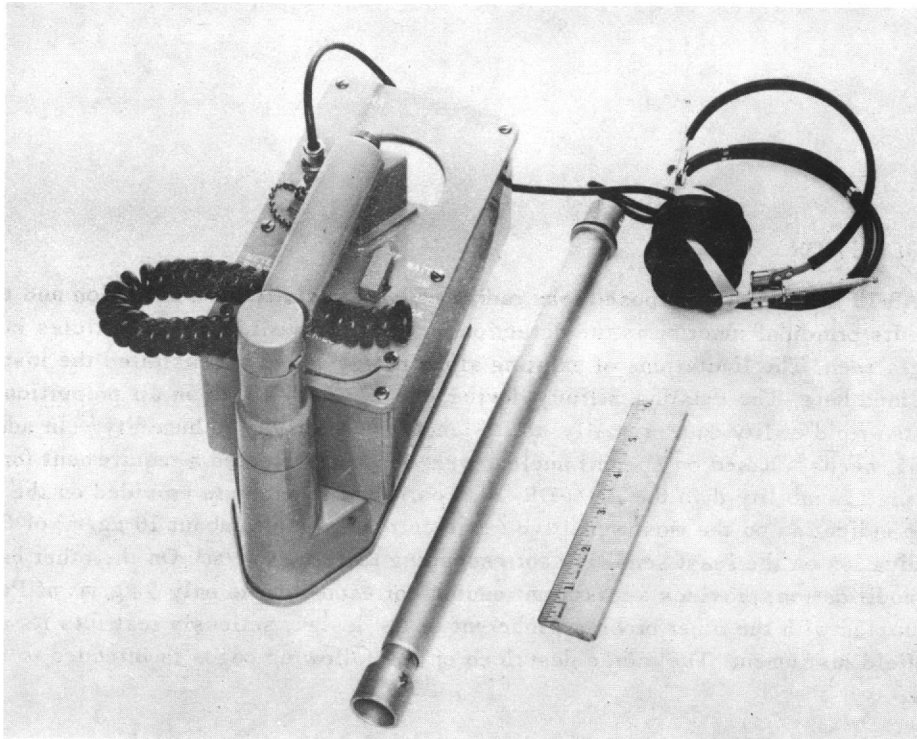


Fig. 1 An Operational RAS-10 Unit



Fig. 2 Use of Probe Handle Extension for Ground Survey

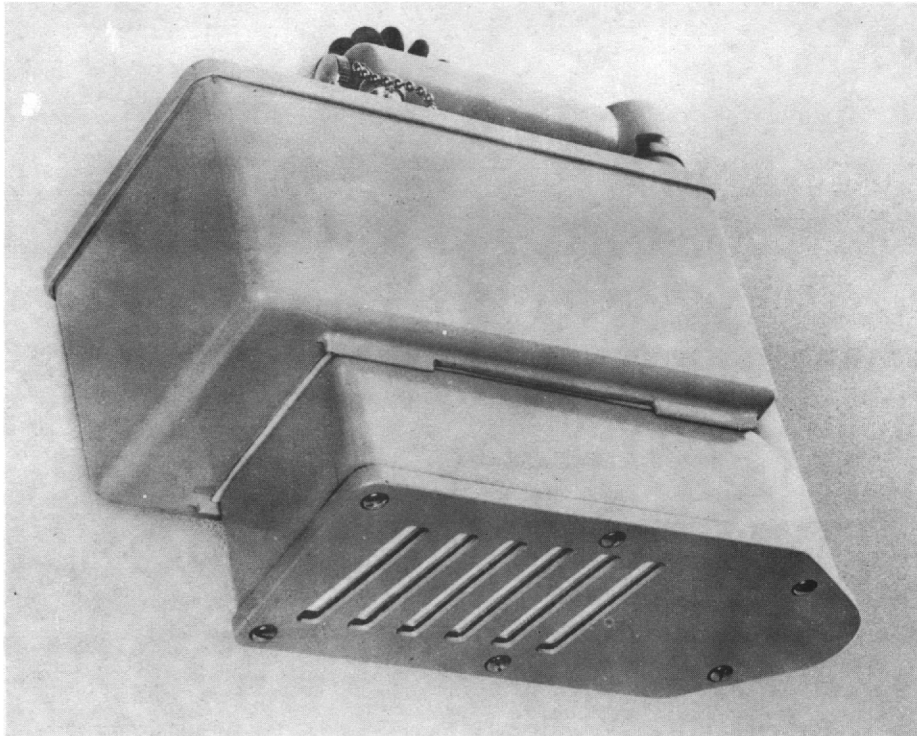


Fig. 3 View of Sensitive Area of Probe

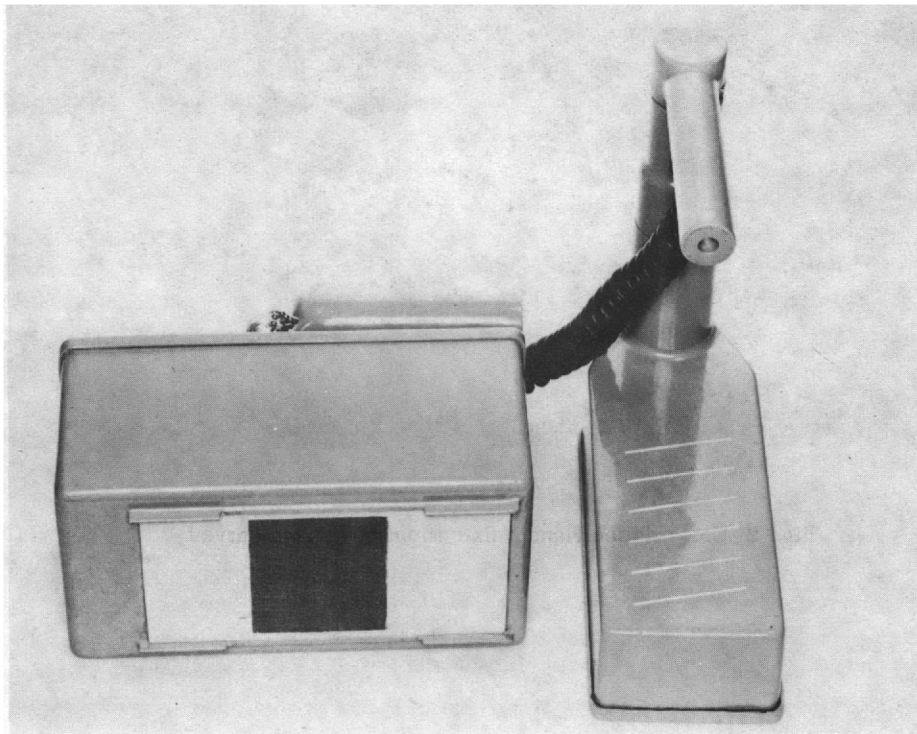


Fig. 4 View of Thorium Check Source

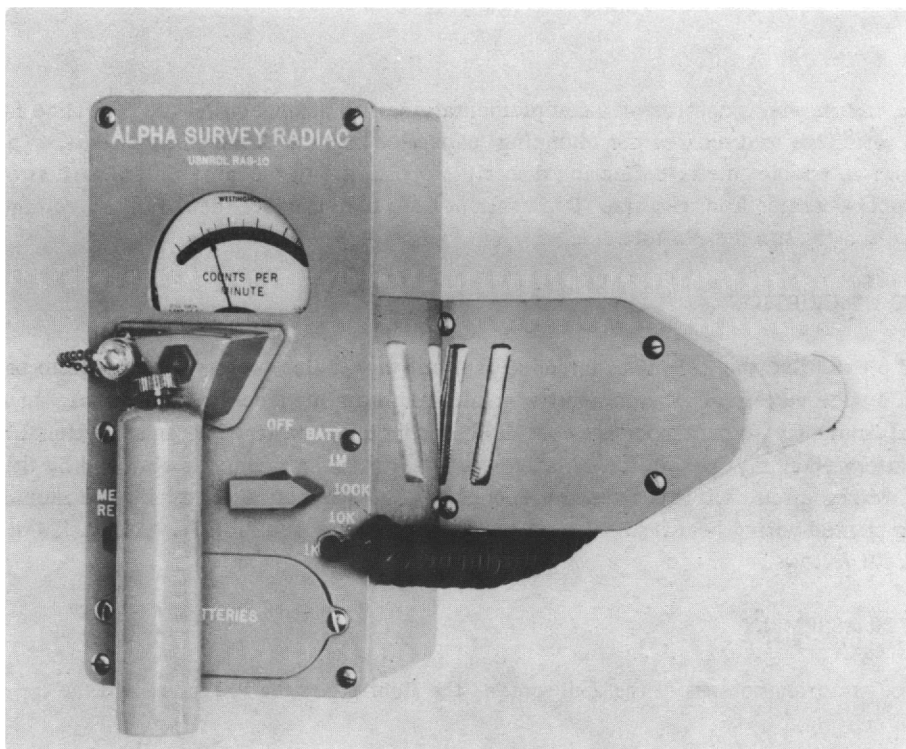


Fig. 5 Operational Check Using Thorium Source

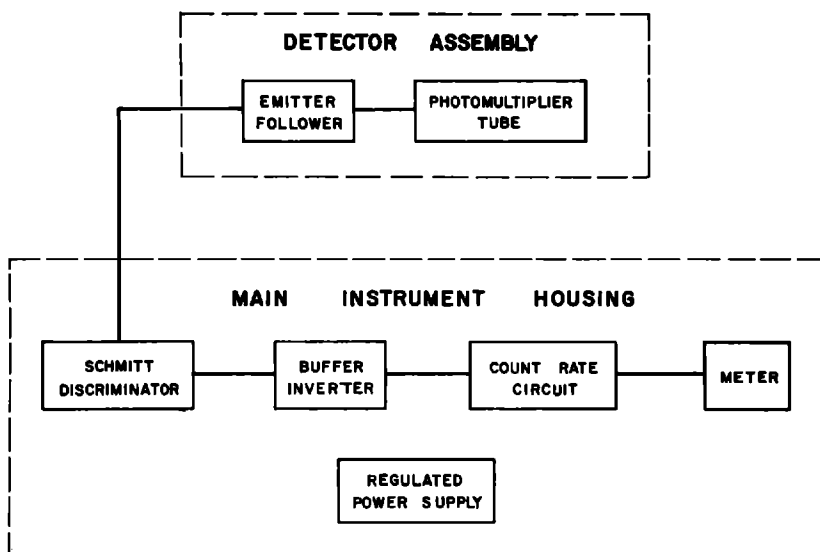


Fig. 6 Block Diagram of RAS-10 Alpha Radiac

the count rate circuit which consists of a complementary pair so arranged that the 'on' time for each input pulse is sufficient to discharge the 'dumping' capacitor into the diode pump circuit. The current produced causes an upscale meter deflection directly proportional to the time rate of arrival of pulses. The power supply operates from two size 'D' flashlight cells and provides the regulated voltages for the transistor circuitry and the PM tube.

4. DETAILED DESCRIPTION

As outlined previously, the RAS-10 is intended as a military radiac prototype designed to perform effectively in a wide variety of environments with minimum maintenance or adjustment. In addition to environmental immunity, other important considerations included battery life and functional packaging. Reasonable battery economy, despite the relative complexity of the radiac, is obtained by the use of a fully transistorized circuit with its attendant economies. Other features of the device include the use of plug-in printed wiring boards to simplify field maintenance (see Fig. 7). A detailed discussion of the instrument follows:

4.1 DETECTOR ASSEMBLY

The detector assembly consists of the ZnS screen, the light pipe, the PM tube, and the transistor emitter-follower.

The screen is a $1/16$ inch lucite plaque coated with a thin layer of ZnS (silver activated) phosphor. Suitable covering for the ZnS surface is of critical importance but the several criteria for selection of a satisfactory medium are incompatible, seriously complicating the problem. Since alpha particles lose a relatively large amount of energy in traversing even thin coverings (on the order of 1 Mev per milligram per square centimeter at 5 Mev) every effort must be made to keep the covering layer to a minimum. Complete opacity is another requisite, since even a small amount of light transmitted through the covering film results in significant instrument response. Further, a reasonable degree of ruggedness and abrasion resistance is essential or an extremely high failure rate will be experienced in field use. Since most of the covering methods commonly in use today leave much to be desired in the areas outlined, considerable effort here was directed towards the development of an improved technique. Based on previous work, direct application or transfer of pure aluminum coatings appeared most promising. Primary emphasis was placed on the transfer method, since surfaces of great toughness appeared feasible. Unfortunately, continuing difficulty was experienced in obtaining reproducible and uniformly pinhole-free coverings. Experience with direct evaporation techniques was also disappointing. Consequently, these methods were abandoned in favor of more standard techniques. The covering medium now used is $1/4$ mil Mylar film aluminized on both sides. This material is preselected for pinhole-free areas and cemented to the screen surface with a low viscosity 100% solids adhesive (see Appendix A). Selection of adequate Mylar is now accomplished by visual inspection in a darkened room. Because of the many uncontrolled variables in this procedure, a more objective technique utilizing photomultiplier tube scanning is now under development. An effort has been made to make removal of the plaque assembly from the instrument probe relatively straightforward to permit replacement of damaged screens in the field. The Mylar covering, while adequate when used with care, is still considered to be only marginally satisfactory, and better techniques must be found to insure true field ruggedness. The light pipe is made of six formed lucite leaves (see Fig. 8). The leaves are in contact with the black surface of the screen and are positioned over slots in the probe base.

Efficiency of light collection requires that the phosphor subtend a large solid angle at the light pipe. Fig. 9 shows that the angle subtended is limited by the critical angle for total reflection in the lucite

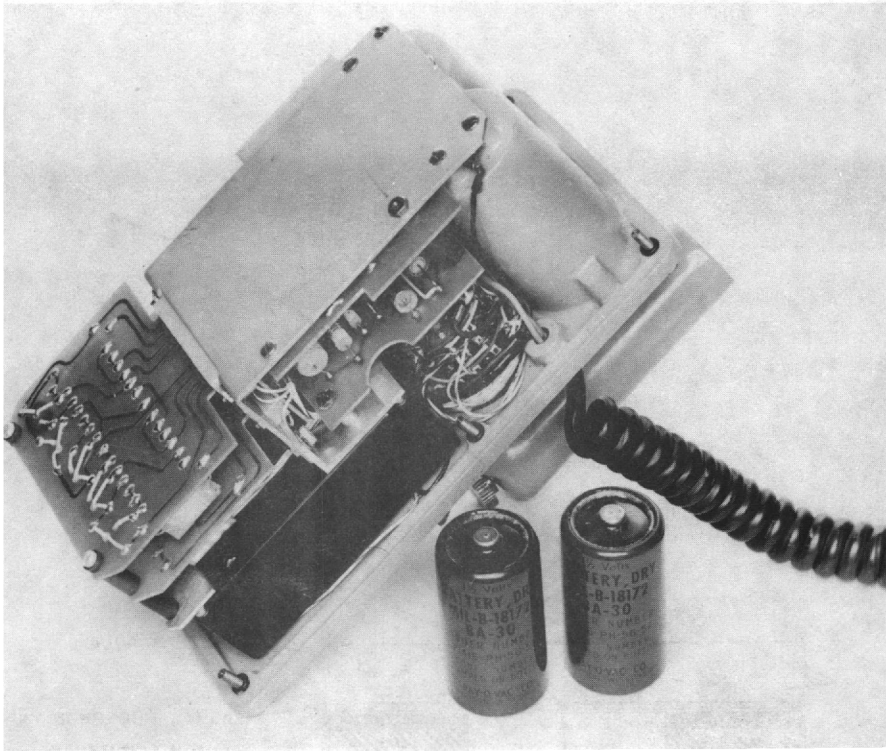


Fig. 7 Electronics Assembly of Main Instrument Housing, Showing Plug-in Printed Wiring Boards

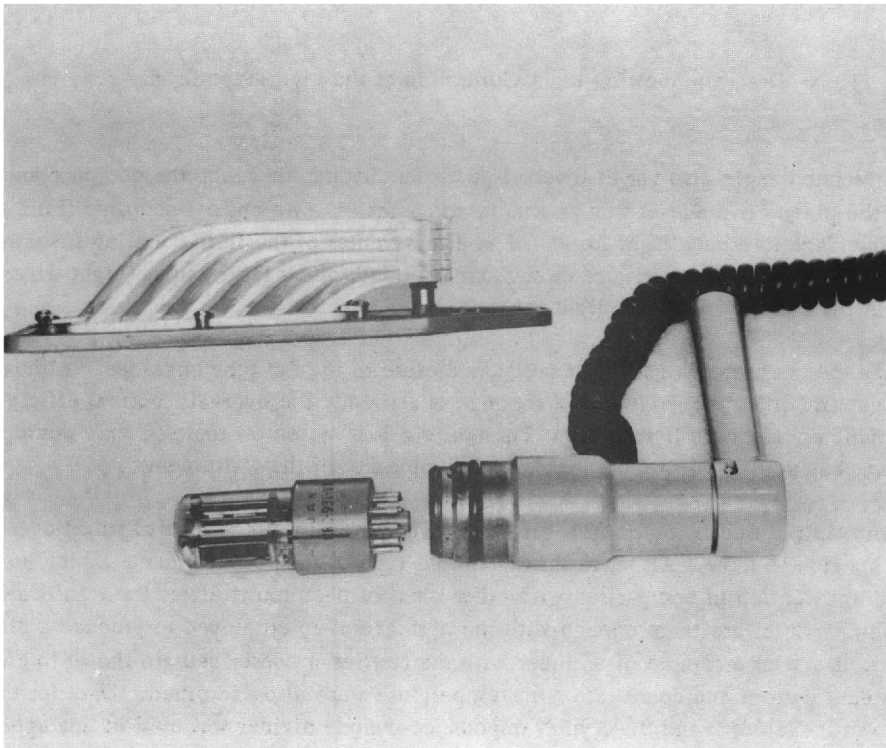


Fig. 8 Probe Disassembled, Showing Light Pipe Construction

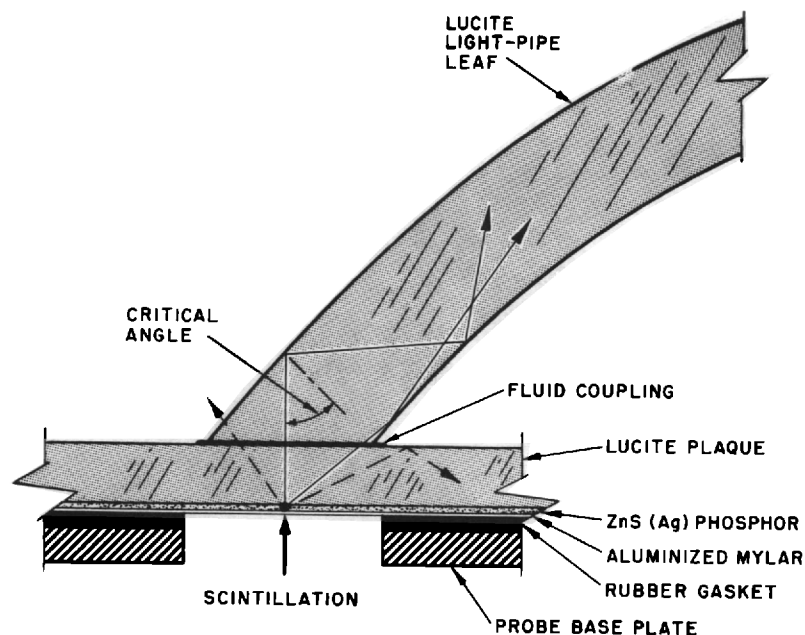


Fig. 9 Diagram Showing Light Collection at the Light-Pipe Leaf.

pipe. The subtended angle also varies inversely with the distance between the phosphor and the pipe entrance, so the plaque is made as thin as structurally practical. An optical coupling fluid* is used at the screen-pipe interface to reduce light losses. The effectiveness of the fluid coupling is shown in Table 1. The cross section of the pipe is constant throughout its length and a large radius (eight times the leaf thickness) is used at the bend to minimize light leakage.

The polished exit surface of the pipe is positioned close to the PM tube envelope. Although only part of the light arriving at the exit end of the pipe is utilized, the over-all optical efficiency is sufficient to provide an adequate light pulse. The use of a lens system at the pipe exit would improve this efficiency, but would add to the expense and complexity of the instrument.

The photomultiplier used is a type 931-VA, an inexpensive nine stage tube of small over-all dimensions and with a side window. Although this particular type of tube tends to have a high noise level and limited amplification in comparison with other types of photomultipliers, the scintillations produced by alpha particles are large enough with the optical set-up employed to produce a usable signal-to-noise ratio. Data for a sample of 25 tubes with the test set-up described are shown in Fig. 10. Variations in dark current and count rate with temperature were also examined. Data for the sample tested are shown in Tables 2 and 3. A high impedance dynode divider was used in this application to minimize total high voltage current drain. To maintain the dynode potentials at high rates, thereby stabilizing gain, capacitors C1, C2, and C3 were employed (See schematic diagram, Fig. 11).

* Dow Corning 200 Fluid, 1,000,000 cs. viscosity.

TABLE 1.
EFFECTS OF SILICONE FLUID COUPLING BETWEEN THE
LIGHT PIPE AND THE ZnS SCREEN ON THE ALPHA SENSITIVITY OF
THE RAS-10 FOR SEVERAL 931-A PHOTOMULTIPLIER TUBES AND LIGHT PIPES.

LIGHT PIPE NO.	RAS-10 METER READING, (10 ³ cpm)					
	Tube No. 32		Tube No. 17		Tube No. 24	
	Without Fluid	With Fluid	Without Fluid	With Fluid	Without Fluid	With Fluid
1	44	82	60	82	68	82
2	34	54	60	74	62	78
3	40	56	—	66	60	75
4	60	72	60	72	68	82

Fluid: Dow Corning 200 (1,000,000 cs. viscosity).

Source: Large-area thin Pu²³⁹.

Discriminator threshold voltage constant for each PM tube.

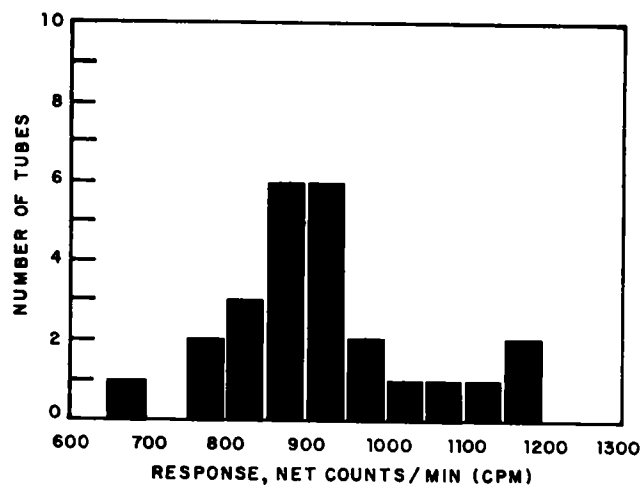


Fig. 10 Distribution of Responses of 931-A Photomultiplier Tubes. Twenty-five tubes tested at standard geometry, using a single leaf of an RAS-10 light pipe and a cellophane tape ZnS scintillant. Source: Pu^{239} with two layers of 1 mg/cm^2 aluminized Mylar absorber. High voltage to P-M tube -- 1000 or 1200 volts. Discriminator at optimum signal-to-noise condition.

TABLE 2.
DARK CURRENT OF 931-A PHOTOMULTIPLIER TUBES
AT ELEVATED TEMPERATURE (53°C).

Dynode voltage divider, 10 megohm resistors (100 megohms total)

No anode load resistor except for microammeter.

TUBE NO.	ANODE DARK CURRENT, (μ a)	
	Supply Voltage = 1000 Volts	Supply Voltage = 1200 Volts
3	3.0	16.0
17	0.6	7.5
30	0.4	4.0
13	—	0.2
25	0.4	1.5
8	0.9	8.0
18	—	0.3
9	—	0.3
29	—	3.5
16	—	0.3
22	—	6.0

TABLE 3.
931-A PHOTOMULTIPLIER (PM) TUBE
RESPONSE VS. TEMPERATURE.

Tests made under standard geometry conditions using a Pu²³⁹ source and a ZnS scintillant.

Supply voltage = 1000 volts.

Discriminator set for zero background.

TUBE NO.	PM TUBE RESPONSE (cpm)	
	-23°C	60°C
4	307	382
26	579	607
32	584	600
10	589	536
20	629	580
18	538	623
22	421	588

Values were experimentally determined at the highest design count rate. The character of the light pulse in this application (fast rise, short duration) causes the amplitude of the output voltage pulse to be a function of the total anode shunt capacity for a wide range of load impedances. Consequently, it was deemed desirable to provide an emitter follower in the probe assembly, thereby effectively isolating the cable capacity from the phototube. To provide a stable output pulse amplitude over the operating temperature range for a given input pulse amplitude, the effects of a varying I_{co} must be minimized. This was accomplished by the use of a suitable fixed bias divider ($R11$ & $R12$) in the base of Q1. The base voltage was set to maintain Q1 in an active condition to achieve maximum sensitivity to the negative input pulses. Performance of the emitter-follower circuit as a function of temperature and supply voltage is shown in *Table 4*.

4.2 Discriminator

The output of the transistor emitter follower is fed to the main instrument housing through a 30" length of coiled cord. The negative pulse developed across $R13$ appears at the base of Q2, turning this transistor on if the pulse amplitude is sufficient to overcome the bias. The resultant positive signal at the collector of Q2 and the base of Q3 tends to cut Q3 off. The regenerative loop closed by $R16$ reinforces the action outlined, driving Q2 into full conduction and turning Q3 off. As long as the input signal persists above the threshold level, Q2 continues to conduct. However, when the signal drops below the threshold level, Q2 ceases to conduct and the circuit rapidly returns to its original state. The action outlined results in the generation of a rectangular negative pulse at the collector of Q3.

The temperature dependence of the Schmitt circuit is shown in *Table 5*. The drift in threshold voltage is caused by the change in the DC base-emitter resistance of the input transistor, Q2, with changes in temperature.

4.3 Buffer Inverter

The negative pulse generated by the discriminator is applied to the base of Q4 through an RC-coupling network consisting of C6 and R21. Q4 is normally biased to cut-off and the input pulse drives it into conduction. An amplified positive pulse appears at the collector.

4.4 Count Rate Circuit

The count rate circuit³ consists of the complimentary pair Q5 and Q6. The action of this circuit is best understood by working backwards from one of the four switch-selected dumping capacitors (C9, C10, C11 and C12). Referring to *Fig. 11*, it can be seen that the active dumping capacitor is maintained in a charged state ($-10v$) and the two transistors are normally non-conducting. The positive pulse from the inverter circuit applied at the base of Q6 causes current flow in the collector of Q6 and the base of Q5. The resultant collector current of Q5 tends to make the base of Q6 more positive which in turn causes more current flow in Q6. This regenerative action rapidly discharges the active dumping capacitor through the loop formed by the emitter-base of Q5, transistor Q6, diode CR3, and the meter circuit. When the discharge current decays to a point where the base current can no longer sustain the collector current of Q5, both transistors are regeneratively switched off. The capacitor then recharges to -10 volts through R23, CR1, and CR2. The amount of charge transferred to the meter circuit for each pulse is directly proportional to the capacitance of the active dumping capacitor, so C9, C10, C11, and C12 are decaded in value from $0.00047 \mu fd$ to $0.47 \mu fd$ for the four ranges of indication. One percent capacitors were used to eliminate the use

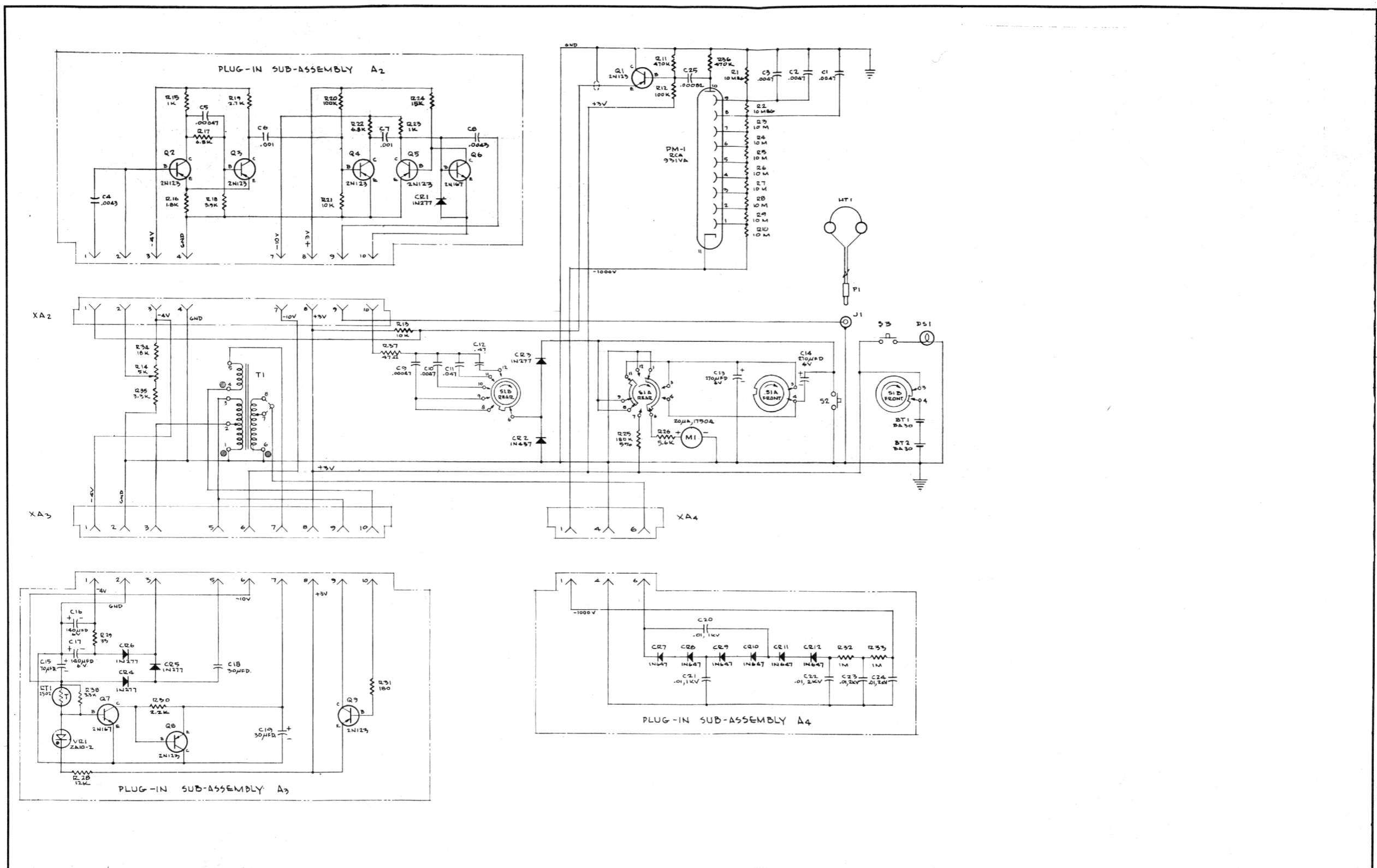


Fig. 11 RAS-10 Schematic Diagram

TABLE 4.

**EMITTER FOLLOWER OUTPUT VS. SUPPLY VOLTAGE, V_B ,
AND TEMPERATURE FOR THE RAS-10**

Input signal constant at 500 millivolts.

Franklin model 370 pulse generator with 100 $\mu\mu$ fd coupling capacitor used for input signal.

Output signal measured with a calibrated oscilloscope.

2N123 TRANS- ISTOR NO.	OUTPUT SIGNAL, (Millivolts)					
	$V_B = 2.0$ Volts			$V_B = 3.0$ Volts		
	-20°C	20°C	50°C	-20°C	20°C	50°C
7	280	280	280	300	300	300
28	280	280	280	300	280	290
40	280	280	290	300	300	300
60	260	260	260	280	280	280
77	270	270	280	290	280	300
115	280	280	280	300	300	300

TABLE 5.

**THRESHOLD VOLTAGE VS. TEMPERATURE FOR
COMBINATIONS OF HIGH AND LOW GAIN 2N123 TRANSISTORS
IN THE RAS-10 DISCRIMINATOR CIRCUIT**

Threshold voltage set to 100 millivolts at 20°C.

Supply voltage constant at -4.0 volts.

Input signal obtained from RAS-10 emitter follower
circuit driven by Franklin Model 370 pulse generator.

TRANS- ISTOR PAIR	THRESHOLD VOLTAGE (Millivolts)		
	-20°C	20°C	50°C
107-7	142	100	70
60-77	127	100	72
60-107	116	100	60
7-77	135	100	69

of a variable resistor for each of the four ranges.

The current produced by repetitive charge transfer from the dumping capacitor to the metering circuit is approximately:

$$I = nCV,$$

where I = current in amperes

n = counts per second

C = capacity in farads

V = charging voltage.

Reasonable reading accuracy and fast response time are the competing factors that determine the choice of tank capacitor in each range. In order to keep the required capacity as low as possible, the series meter resistor was also used. Here, again, selection of too large a resistor results in serious non-linearity as a function of count rate, because the charging voltage will decrease with increasing rate. The fractional probable error due to the random arrival of pulses is given by:⁴

$$\text{P.E.} = 0.67 \times \frac{1}{\sqrt{2nRC}},$$

where n = counts per second

R = R26 + meter resistance

C = C13 + C14

In the case of the RAS-10, the worst situation is encountered on the most sensitive or 0 to 1000 CPM range. At mid-scale on this range, the probable error is about 10% with the circuit values employed. Considering the application of the instrument, this is a tolerable probable error.

4.5 Power Supply

The power supply is basically a transformer coupled relaxation oscillator with a feedback regulating system similar to that described by Eklund and Work.³ Transistor Q9 and transformer T1 are connected to form a blocking oscillator circuit. The primary winding of T1 is connected to the collector of Q9, and the secondary is connected to the base to provide regeneration. The circuit operates on the flyback principle, and power is delivered to the output during both the 'on' time of transistor Q9 and the flyback period of the transformer.

The -4 volt supply for the Schmitt circuit is obtained by rectifying the flyback voltage at the center tap of the primary winding. The -10 volt supply for the count-rate circuit is taken from the primary winding, and the high voltage for the PM tube is obtained from the tertiary winding of T1.

The -10 volts, the high voltage, and the input battery power of the supply are all stabilized by the feedback regulating circuit (VR1, Q7, and Q8). The -10 volt output is compared to the Zener reference diode, VR1, and the error signal is amplified by transistors Q7 and Q8. The DC output voltage of Q8 is used to control the bias voltage on the base of the oscillator transistor, Q9, so that the -10 volts is stabilized and the input power to the supply remains proportional to the output power regardless of changes in battery voltage or variations in output loads. A voltage tripler circuit is used in the high voltage section and one-half of a voltage tripler is used in the -10 volt output so that these voltages

are directly proportional. Since the -10 volt output is stabilized by the feedback circuit, the high voltage is also regulated.

The transformer turns ratio is 1:0.9:57 with 180 turns in the primary winding. The tertiary winding was tapped at a turns ratio of 1:46 so that the high voltage could be set to either 1000 volts or 1200 volts. An Arnold Engineering Co. type AL 4 selectron core with a 0.002" air gap was used. The windings were layer wound with 0.0005" mylar interlayer insulation to minimize the losses due to distributed capacitances in the tertiary winding. Two 400 volt silicon diodes (1N647) were used in series in place of a single higher voltage diode in the high voltage tripler circuit. This was done to prevent thermal runaway of reverse leakage currents at high temperatures.

Since most of the errors caused by changes in supply voltages are cumulative, it is necessary to keep the power supply stable with respect to temperature. Nearly all of the variations in supply voltages with temperature are due to the temperature dependence of the reference diode, VR1. To compensate for this, thermistor RT1 was added to the regulating circuit. The effects of the thermistor on the stability of the power supply over the operating temperature range are shown in Fig. 12.

The characteristics of a breadboard power supply circuit are shown in Figs. 13 and 14. Figure 13 shows the effects of the feedback regulating circuit on the input power and efficiency of the power supply. Figure 14 shows that the regulation of the high voltage and -10 volt outputs extended well below the nominal battery end point (2.4 volts) of the instrument. The reason for the inverse regulation characteristic of the -4 volt output is that the peak to peak transformer voltages are clamped by the regulating system, so the flyback voltage (negative peak) increases as the battery voltage decreases.

5. CALIBRATION

It is recommended that the instrument be calibrated using a thin, uniformly distributed source of Pu^{239} . Overall dimensions of the source should be large enough to provide complete coverage of the sensitive area. The actual source disintegration rate should be sufficient to provide deflection on the 100,000 cpm range, approximately $600 \mu\text{g}/\text{m}^2$ being desirable. The instrument should be placed on the source in a jig arranged to provide $1/32$ " clearance between the probe face and the source to ensure reproducible positioning.

The tap on T1 (see Fig. 11) should be in the low voltage position (terminal 7). Then potentiometer R14 should be adjusted so that the desired meter reading is obtained. Since $1000 \mu\text{g}/\text{m}^2$ corresponds to full scale on this range, the desired indication is the source activity in micrograms per square meter times one hundred. During the adjustment, the DC voltage between the base and the emitter of Q2 should be monitored and not allowed to go lower than 100mv (base positive with respect to emitter). If a proper adjustment cannot be made, the tap on T1 should be moved to terminal 8 and the procedure repeated. When the setting is properly made, the background pulse rate measured at the headphone jack should be less than 15 pulses per minute.

Caution must be observed in allowing sufficient time after the phototube and/or scintillant has been exposed to light for the phosphorescence to decay to a tolerable level⁵. The phosphorescence of a ZnS screen continues for about two hours after exposure to normal room light. Although the background rate may drop to zero in a few minutes, the calibration of the instrument may drift for as long as two hours. Figure 15 shows the drift in alpha sensitivity and background rate of a ZnS screen after five minutes exposure to normal room light.

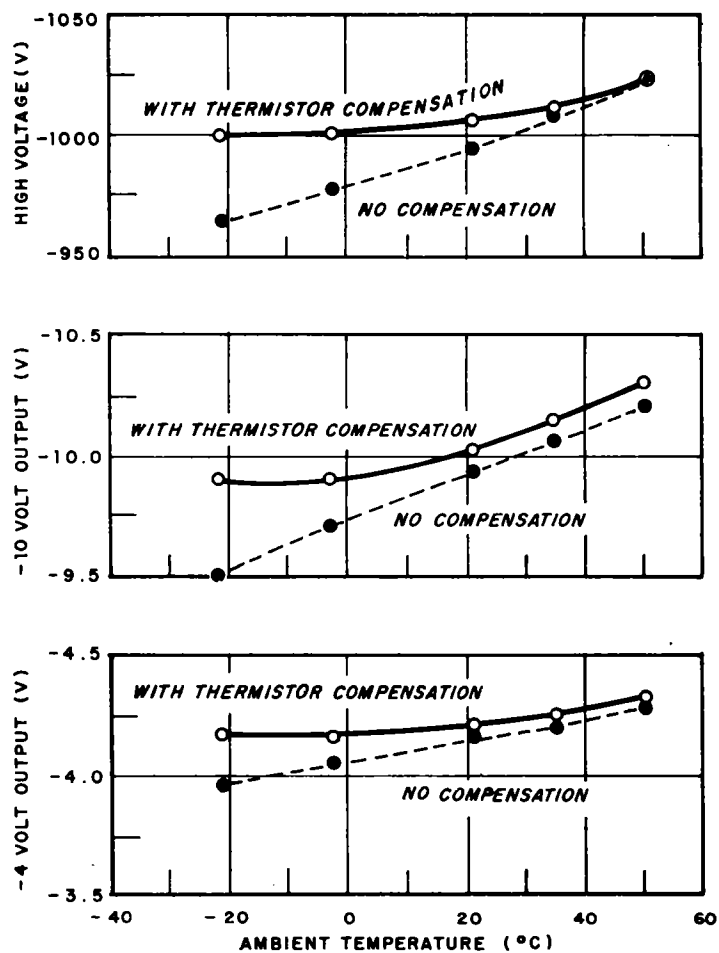


Fig. 12 Effects of Thermistor Compensation on RAS-10 Power Supply Temperature Dependence. Measurements under operational load. Transformer T1 tap No. 7 used. Internal batteries.

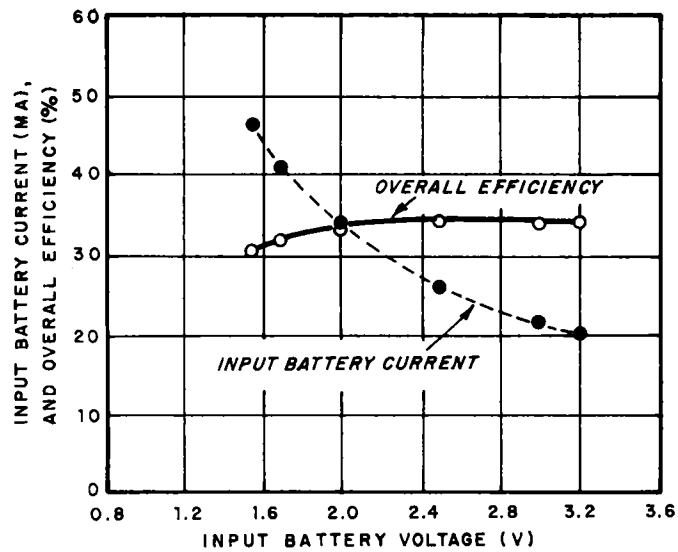


Fig. 13 RAS-10 Power Supply Characteristics, Breadboard Model, Using a Low Voltage D-C Power Supply instead of Batteries. Resistive Loads of 100 megohms, 40 k ohms, and 2.7 k ohms, respectively, on high voltage, -10 volt, and -4 volt outputs.

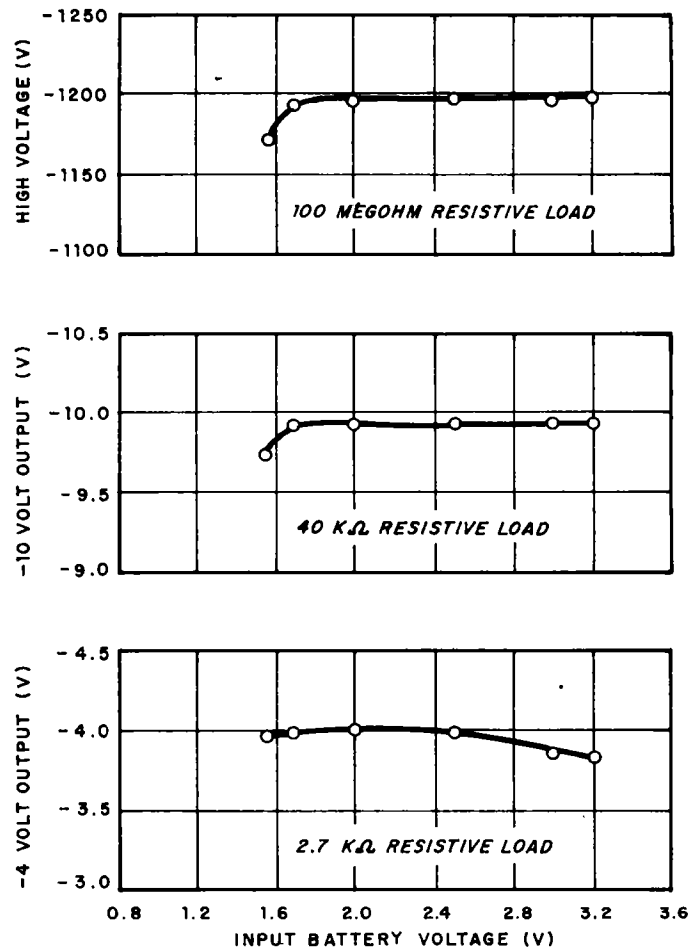


Fig. 14 Output Voltage Regulation vs. Input Battery Voltage, RAS-10 Power Supply, Breadboard Model, Using Low Voltage DC Power Supply Instead of Batteries. Resistive loads represent maximum predicted operational load in the instrument.

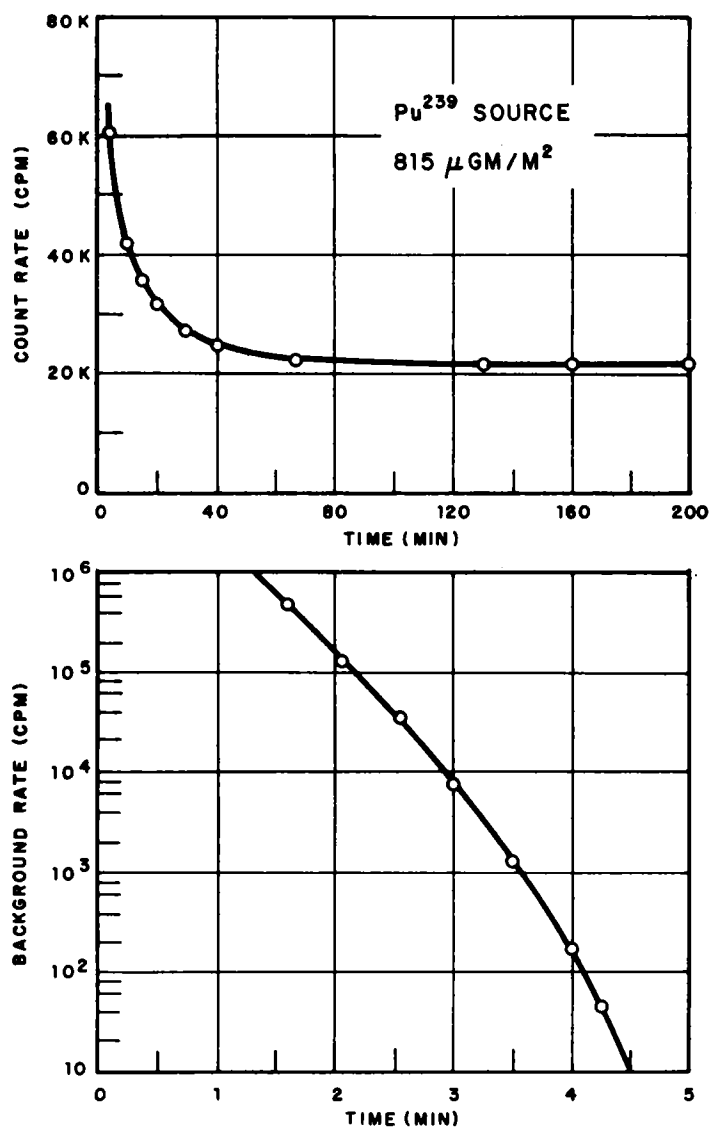


Fig. 15 Alpha Sensitivity and Background Rate of RAS-10 ZnS Screen After 5 Minutes Exposure to Normal Room Light.

6. PERFORMANCE

Due to the character of alpha radiations, it is extremely difficult to control all of the factors external to the instrument that influence accuracy and reproducibility. Since, as has been pointed out previously, alpha particles have an extremely short range in air (a few centimeters), small differences in effective instrument-source geometry caused by changes in spacing, thin moisture layers, or other similar overcovering make large differences in successive readings, thereby making reproducibility difficult. These factors complicate making meaningful performance tests even under laboratory conditions and the problems to be anticipated in typical field circumstances are far more severe. Temperature tests over the military range from -40° to 50°C , for example, are complicated seriously by the formation of condensate on the instrument "window" and/or the alpha source. However, with suitable care useful data can be obtained. Figure 16 shows the results of a temperature test made on an instrument both with and without thermistor compensation in the power supply. The temperature dependence of the compensated instrument is due mainly to changes in the threshold level of the Schmitt discriminator and to changes in the gain of the emitter-follower circuit. It can be seen in Fig. 16 that the error in meter indication at -20°C exceeded the $\pm 20\%$ accuracy specification. However, for operation at very low temperature, the thorium check source can be used to determine the error in calibration and a correction factor can be applied to measurements made.

Actual alpha efficiency, defined as the ratio of true instrument alpha counts to the number of 4 π disintegrations occurring from a known source under the active screen area, is about twenty per cent. Meter indication, however, is adjusted to yield full scale indication on the highest range (10^6 CPM) for $10,000 \mu\text{g}/\text{m}^2$ of Pu^{239} . The apparent percentage efficiency, E' , is given by:

$$E' \text{ (percent)} = \frac{\text{Meter indication (CPM)}}{\text{Active screen area} \times \mu\text{g}/\text{cm}^2 \times 1.37 \times 10^5 \text{ dpm}/\mu\text{g}} \times 100 = \frac{10^6}{17 \times 1 \times 1.37 \times 10^5} \times 100$$

$$= 43\%$$

For accurate measurement of alpha emitters other than plutonium, it is first necessary to standardize the instrument for the isotope in question; i.e., determine a new apparent efficiency in each case. Then, determinations can be made provided that the active material is deposited as a thin source (small self-absorption) and is uniformly distributed over the full screen area. Further, the calibrating geometry must be accurately duplicated. Clearly, the conditions imposed preclude measurement of any alpha emitter except under very carefully controlled conditions. In the field, use of approximate attenuation factors for various surfaces is, at the present time, the only mechanism for obtaining an estimate of surface contamination with an alpha radiac. When laboratory type conditions justify it and the appropriate apparent efficiency, E , is known, as outlined above, the disintegration rate is given by:

$$\text{dpm}/17 \text{ cm}^2 = \frac{\text{CPM (Indicated)}}{E} \times 100$$

The response of the RAS-10 to beta-gamma radiation varies, depending on the particular phototube used. Beta response is produced by interaction with the ZnS scintillation-screen while the principal cause of gamma response appears to be fluorescence in the 931-A glass envelope. The individual beta pulses produced are small and "pile-up" is required to overcome the discrimination threshold. Consequently, the magnitude of response is a function primarily of the noise level in the phototube used. Gamma efficiency is also a function of the noise level but the properties of the individual tube envelope are equally important. The typical beta response ranges from about 20 to 200 CPM/rep/hr for Sr^{90} , and gamma response ranges from about 500 to 5000 CPM/t/hr for Co^{60} .

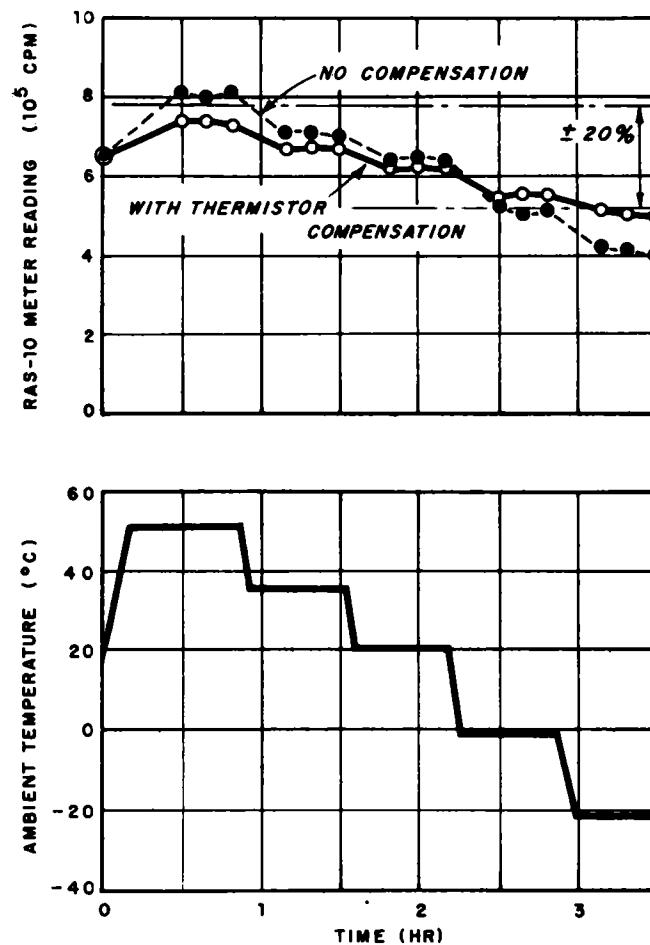


Fig. 16 Over-all RAS-10 Performance vs. Temperature, Compensated and Uncompensated. Source: Large-Area thin Pu²³⁹. Internal batteries.

A detailed evaluation of two RAS-10 units was made at USNRDL.⁶ The units tested performed satisfactorily under vibration, humidity, and altitude tests, and maintained calibration after undergoing the high and low temperature storage test and the shock test. The battery life with the meter light on ten percent of the time was in excess of 50 hours. The results of the operational temperature tests were essentially the same as shown in Fig. 16. The main instrument housings of both units leaked during the submersion tests; however, this was corrected by minor design modifications. The tests also showed that the instrument response to low energy x-rays is excessive. About 0.7 r/hr of 70 Kev (effective) x-rays is sufficient for full scale indication on the 10^5 CPM range. However, the tests indicate that a simple lead filter around the PM tube housing will eliminate this difficulty.

7. CONCLUSIONS AND RECOMMENDATIONS

The overall performance, ease of operation, and extended operating range of the RAS-10 represents a significant improvement over the AN/PDR-10. Instrument performance, except for low temperature operation and gamma response, appears to be satisfactory. The meter errors at low temperatures are not serious, however, and useful measurements can be made by using the thorium source as a calibration check. The laboratory plans to design a lead filter to reduce the response to low energy x-rays, and further work will also be done to provide accessory probes for use in special applications.

Approved by:



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Head, Nucleonics Division

For the Scientific Director

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APPENDIX A SCREEN FABRICATION

The screens are made in four steps: (1) applying ZnS on Plexiglas, (2) trimming the screens to proper size, (3) bonding the Mylar film to the ZnS surface, and (4) coating the Mylar film for corrosion resistance. The apparatus was set up so that the screens could be made in batches of six. The time required to process a batch is one week. There are no critical steps in the process and production techniques could be easily adapted if large quantities of screens are to be produced. The fabrication process used at this Laboratory is described in detail below.

Applying ZnS on Plexiglas

1. Construct a closed wooden box (1/4" plywood) approximately 20" wide, 28" long, and 15" high. Leave the front panel solid to a height of about 8" from the bottom of the box. The remainder should be hinged and clamped so that it may be kept tightly closed when not in use. (This is to ensure a saturated ethylene dichloride atmosphere inside the box when making the screens.)
2. Construct a wooden bench about 12" square by 4" high in the center of the box. Fill the interstitial space around the sides of the bench with waste cotton. The top of the cotton should be below the level of the bench.
3. Make a 4% solution by weight of Plexiglas II-U.V.A. in reagent ethylene dichloride (180 grams of Plexiglas in 4 kilograms of ethylene dichloride). A more uniform result will be obtained if this solution is made in large quantities instead of a number of small lots. The procedure is as follows:
 - a. Clean a large sheet of plastic and a one gallon mixing bottle with acetone.
 - b. Cut the plastic into 1/8" strips with a clean wood saw.
 - c. Place the plastic & mixing bottle in an oven at 200°F for one hour to dry. (If moisture in sufficient quantities is allowed to remain, the resultant solution will turn milky; this will result in absorption of light from the phosphor.)
 - d. Combine the weighed quantities of Plexiglas and ethylene dichloride, and place the mixing bottle on an electric shaker table until all plastic is dissolved. (This requires about 8 hours.)
4. Cut a 1/16" Plexiglas II-U.V.A. sheet into 7" diameter disks.
5. Clean both surfaces of the disks with acetone, and then wipe dry with lint-free lens tissue. Make sure that the surface of the plastic is reasonably dust-free before proceeding.
6. Saturate the cotton with ethylene dichloride; technical grade is sufficient. A saturated atmosphere must be maintained in the box while pouring on the bonding solution and applying the phosphor coating, to prevent solvent evaporation from the solution and thus obtain a uniform coating of phosphor. To maintain a saturated atmosphere, keep the door closed between applications of the bonding solution and phosphor.

7. Place a disk in the ethylene dichloride atmosphere; allow it to remain for about one minute.
8. Pour approximately 35 cc of the 4% solution of Plexiglas in ethylene dichloride in the center of the disk.
9. Tilt the disk slightly to flow the solution evenly over the surface. Be sure to flow the solution almost to the edge but not over. Flowing over will cause the zinc sulfide film to crack.
10. Allow the solution to settle for one minute with the box closed.
11. Dust the disk with zinc sulfide, silver activated, powder* using a hand atomizer. Cover the area thoroughly. Any excess powder may be removed after the bonding medium has dried.
12. Remove the disks from the box and dry for 24 hours at room temperature. Heating should not be used to accelerate the drying; heating causes pock marks to occur on the surface on the phosphor.
13. Remove the excess zinc sulfide with a clean brush.

Trimming the Screens to Proper Size

1. Machine the screens to the desired size and shape. The screens should be kept free from oil and grime and the surfaces protected with soft filter paper masks.
2. Stack the finished screens between smooth, flat metal plates and heat at 200°F for one hour; then allow them to cool slowly to room temperature. This is necessary to remove stresses caused by machining and by applying the coating.
3. Sand the phosphor coating with fine emery cloth (150 or finer).

Bonding the Mylar Film to the ZnS Surface

1. Construct a vacuum table as per attached drawing (*Fig 17*)
2. Prepare a template of the same size and shape as the screens and remove the areas corresponding to the window areas of the instrument.
3. Mark off the window areas on the surface of the phosphor with a hard (6H or harder) pencil to delineate the area where the adhesive will be applied.
4. Throughout all of these processes, be sure to keep both surfaces of the screens clean by using soft filter paper masks.
5. Cool the screens to approximately 0°F
6. Inspect a sheet of 1/4 mil, double coated aluminized Mylar over a light table equipped with a bright light source and a clean glass top. Mark off areas which are free of pin holes (Perform this step in a darkened room.)
7. Stretch the Mylar over the rubber mat on the vacuum table and tape down edges with masking tape;

**i.e. RCA zinc sulfide, silver activated*

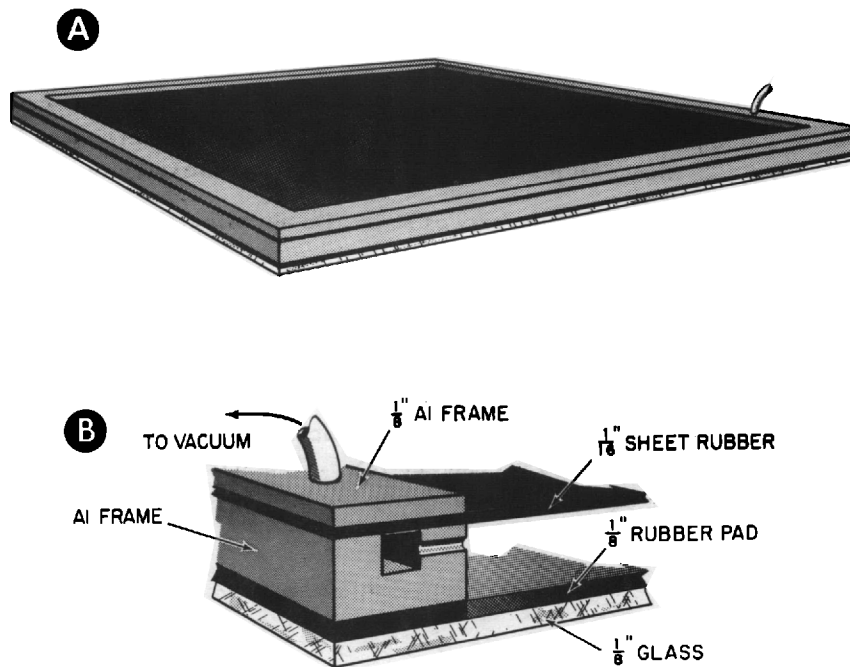


Fig. 17 Vacuum Table Used in Conjunction with Bonding Aluminized Mylar to Scintillation Screen. A. General View. B. Detailed Cross-section.

it may be necessary to retape some of the sides to obtain a smooth, wrinkle-free film. (Do not stretch too much or the aluminum film will become cracked.)

8. With a fine camel's hair brush, apply a thin coat of low-viscosity, 100% solids adhesive which will cure at room temperature under contact pressure*. Some spreading can be anticipated; consequently, areas slightly larger than the windows must be kept free of adhesive. All other areas should be covered with a thin, even coat.

9. Place the adhesive coated screens over the areas that are free of pinholes, set the cover in place, and apply the vacuum.

10. The screens must be kept cold (0°F or below) until the adhesive has cured. To accomplish this the entire unit may be placed in a cold atmosphere or dry ice, metal blocks, etc., may be placed on the rubber vacuum cover; 1/2" aluminum plates cooled below 0°F are satisfactory.

11. After the adhesive has cured, trim off the excess mylar. Do not allow anything to touch the exposed surface of the Mylar.

Coating the Mylar Film

1. Coat the surface of the Mylar with a film forming silicone compound**. It may be necessary to thin the silicone compound. A mixture of 40 grams of ethyl acetate, 6.25 grams of 30% film forming silicone compound, and 0.15 grams of hardener produced a satisfactory film. The film was dried in air overnight and cured for 30 seconds at 325°F. The screens were placed on cold metal sheets to prevent softening of the Plexiglas during the heat cure.

**i.e., Helix Bonding Agent 823 manufactured by the Carl H. Biggs Company, Inc., Los Angeles, California*

***i.e., Dow Corning #23*

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